Activating Brain Systems for Syntax and Semantics

Human languages consist of multiple types of elements: phonemes, words, syntactic structures, intonational contours, etc. Are particular regions of the brain specialized for representing and/or processing these different elements? Dapretto and Bookheimer (1999 [this issue of *Neuron*]) have addressed this question in the domains of word meaning (lexical semantic representations) and sentence structure (syntax), using functional magnetic resonance imaging (fMRI).

In Dapretto and Bookheimer's study, subjects made judgments about the synonymity of two sentences. Two conditions were presented. In the first condition, the sentences had the same form but had one change in vocabulary. Subjects were to say that the sentences were the "same" if the different words were synonyms (e.g., "the lawyer questioned the witness," "the attorney questioned the witness") and that they were "different" if they were not (e.g., "the man was attacked by the doberman," "the man was attacked by the pitbull"). In the second condition, the words in the sentences remained the same but the syntactic structure of the sentence changed. Subjects were to say that the sentences were the "same" if the thematic roles (agent of the verb, theme of the verb, theme of a preposition) did not differ (e.g., "the policeman arrested the thief," "the thief was arrested by the policeman"). They were to say that the sentences were "different" if there was a change in thematic roles (e.g., "the teacher outsmarted the student," "the teacher was outsmarted by the student"). Subjects saw the same number of active and passive sentences in each condition. The first condition activated Brodmann's area (BA) 47, both against a baseline resting condition and against the second condition. The second condition activated BA 44, both against a baseline resting condition and against the first condition. Dapretto and Bookheimer say that the first condition requires lexical semantic processing and the second condition requires syntactic processing. They therefore conclude that BA 47 is specialized for representing and/or processing lexical semantic information and BA 44 for syntactic structure.

Some but not all studies have found the same localizations as Dapretto and Bookheimer. Results from our lab (Stromswold et al., 1996; Caplan et al., 1998, 1999) are consistent with Dapretto and Bookheimer's in the area of syntactic processing. We found that only Broca's area (BA 44 and 45) was activated when subjects made judgments about the plausibility of sentences with object-relativized relative clauses (e.g., "the juice that the child spilled stained the rug" versus "the child that the juice spilled stained the rug") compared to when they made these judgments about syntactically less complex sentences with subject-relativized relative clauses (e.g., "the child spilled the juice that stained the rug" versus "the juice spilled the child that stained the rug"). In contrast, Just et al. (1996) found more regions of activation when subjects undertook a somewhat different task that involved syntactic processing. Just et al. had subjects read a sentence that varied in syntactic complexity. The harder experimental condition contained object-relativized sentences and the simpler baseline condition contained subject-relativized sentences; the exact sentence types were slightly different than those used in our studies. Subjects then read a second sentence and indicated whether that sentence described the meaning of the first sentence (e.g., statement: "the general that the politician introduced praised the reporter"; test: "the general introduced the politician"). Just et al. found activation in Wernicke's area (BA 22) as well as Broca's area and in the right hemisphere homologs of these regions. Similar discrepancies have been found in studies of lexical semantic processing (Peterson et al., 1988; Demonet et al., 1992; Vandenberghe et al., 1996).

Why do these differences arise, and what can be done to resolve them?

Different results could be due to technical factors: different sensitivities of positron emission tomography (PET) and MR techniques, inaccuracies inherent in normalization of individual brains affecting discernible activation in a region of interest, different statistical techniques in use in different laboratories. In principle, these differences can be resolved by reanalysis of data, efforts to replicate experiments using different technology and analyses, etc. But this seems unlikely to be the whole story. The differences between the results of Dapretto and Bookheimer and those of Just et al., for instance, do not seem likely to be entirely due to different ways of determining where Wernicke's area is, or whether blood oxygen level–dependent (BOLD) signal changes significantly in that region.

Different results could also be due to differences in the subjects tested. In general, most activation studies have tested right-handed college students, but little is known about other characteristics of the subjects, some of which may affect the localization of language processing systems. Familial handedness profiles may be relevant and may differ in different groups studied. There are data that suggest that differences in language processing efficiency are associated with different event-related potential correlates of aspects of language processing (King and Kutas, 1995); the language processing proficiency of the subjects in most PET and fMRI studies is not known. These and other factors may affect activation results in language studies.

Finally, different results could also be due to differences in tasks. We can illustrate this by considering Dapretto and Bookheimer's results. As these authors say, their second condition requires syntactic processing. But it also requires determination and comparison of thematic roles. Perhaps BA 44 is involved in these functions, not syntactic analysis itself. Finally, the effect reported by Dapretto and Bookheimer is a difference between the BOLD signals that occur when subjects make two different types of comparisons, and therefore is not necessarily a direct reflection of the processes that are required in either of the comparisons themselves. In contrast, our results could have been related to making plausibility judgments, and Just et al.'s to subjects retaining the form of the target sentence in memory, perhaps through the use of rehearsal. Dapretto and Bookheimer point out that the effects reported by our group and by Just and his colleagues may have been due to overall complexity and working memory load, not to the processing requirements of specific syntactic processes.

Difficulties in interpreting tasks are not restricted to studies of syntax. The first experiments that studied lexical semantic processing compared generation of a verb associated with a noun (e.g., saying "sweep" when hearing the word "broom") with repeating a noun (i.e, saying the word "broom" after hearing that word) (Peterson et al., 1988), but this comparison involves many functions other than semantic processing (e.g., shifting categories). No one experiment isolates a single linguistic operation; differences across experiments may reflect differences in processing linguistic representations in different tasks. This invites the development and testing of more detailed psychological processing models, which consider both type of representation and task.

New imaging technologies have vastly increased our ability to search for the neural systems that support lexical semantic and syntactic processing. We seem to be steadily homing in on the location of these systems. Dapretto and Bookheimer have moved us a step closer to this goal.

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Selected Reading

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